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ANNUAL PROGRESS REPORT
July 1, 2003 through June 30, 2004

EVALUATION OF GROWTH AND SURVIVAL OF DIFFERENT GENETIC STOCKS OF MUSKELLUNGE: IMPLICATIONS FOR STOCKING PROGRAMS IN ILLINOIS AND THE MIDWEST

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Submitted to
Division of Fisheries
Illinois Department of Natural Resources
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Principal Investigator	Center for Aquatic Ecology

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EXECUTIVE SUMMARY: Muskellunge are an important sportsfish that are commonly stocked throughout Illinois and much of the Midwestern United States. In Illinois, as in many other states, the demand for these fishes far exceeds the supply. Stocking has become the primary management tool for establishing and maintaining muskellunge populations. The high costs associated with producing these fishes create the need for efficient management practices. Previous research efforts have determined the size of fish and timing of stocking to maximize growth and survival. However, additional information on muskellunge stocking strategies is needed. Specifically, more biological data on different genetic stocks of muskellunge is needed to determine the best population to stock in a particular body of water to maximize growth and survival.

Morphological and geographic characteristics have suggested multiple distinct groups of muskellunge. More recently, genetic analysis identified several different genetic stocks of muskellunge (Ohio River drainage, Upper Mississippi River drainage, and the Great Lakes drainage stocks), each with multiple populations. Previous work with young-of-year from these populations found differences in growth and food consumption as a function of temperature. As a trophy species, anglers and managers are interested in using populations of fish that grow the fastest, live longest, and obtain a largest maximum size. Because muskellunge populations are either not naturally found or have been eliminated in many Illinois lakes and reservoirs, it is not clear which population to use in stocking efforts. The muskellunge population currently used as brood stock for the stocking program in Illinois is of an unknown origin and may be made up of several different populations. Muskellunge stocks from various populations may perform differently in Illinois waters in terms of growth and survival. Additional information is needed on differences in growth and survival among stocks in waters at varying latitudes in Illinois before management recommendations can be made on which stock is most appropriate. Determining which stock has the highest levels of growth and survival under the various conditions found in Illinois waters will increase stocking success and angler satisfaction. This study examines differences in growth and survival among different stocks of muskellunge in order to make recommendations regarding stocking in Illinois.

During segment two, all activities outlined in the annual work plan were accomplished and were completed within the specified budget. During this segment, two jobs related to muskellunge stock evaluation were completed. Those jobs are (1) evaluation of growth and (2) evaluation of survival among stocks of muskellunge. In this segment of the study, we compare growth and survival of muskellunge from the Upper Mississippi River drainage stock, the Ohio River drainage stock, and the Illinois North Spring Lake progeny in three lakes throughout Illinois. Muskellunge fingerlings from each of the stocks were introduced into Pierce Lake, Lake Mingo, and Forbes Lake at rates ranging from 1.0 – 8.2 fish per hectare during fall 2003. Initial mortality due to transport and stocking was assessed using three 3-m deep predator-free cages for 48-h. Mortality from stocking stress was low for all populations. Across years and reservoirs, the Upper Mississippi River drainage stock muskellunge appear to have slower mean daily growth and mean relative growth rates than the Ohio River drainage stock or the Illinois population. The Illinois and Ohio River drainage stock muskellunge generally have similar mean daily growth and mean relative growth rates. Of the two, the Illinois population typically exhibited slightly higher growth rates. Initial results from reservoir introductions suggest that the Ohio River drainage stock muskellunge have slightly higher survival than the other populations and stocks. These introductions will need to be monitored over several years to further assess growth and survival differences among stocks.

In pond experiments at the Sam Parr Biological Station, Marion County, Illinois, three 0.4-ha ponds were also used to evaluate growth and survival differences among muskellunge stocks. At draining in April 2004, the Illinois population and the Ohio River drainage stock had similar mean daily growth rates over the 6-mo interval, and both were higher than the mean daily growth rate of the Upper Mississippi River drainage stock. The Ohio River drainage stock muskellunge exhibited a significantly higher mean relative growth rate than both the Illinois population and the Upper Mississippi River drainage stock. Upon draining in April 2004, no significant differences in survival over the 6-mo period from stocking until draining were observed among muskellunge stocks.

These same, as well as additional populations of muskellunge will be evaluated for growth and survival differences in future years of the study. The results obtained from these first two years will be combined with those from future years to identify the long-term growth and survival differences among genetic stocks of muskellunge. These results will be used to develop guidelines for future stockings that maximize growth, survival, and angler satisfaction in reservoirs throughout Illinois.

Job 101.1. Evaluating growth of different stocks of muskellunge.

OBJECTIVE: To determine differences in growth among various stocks and populations of muskellunge in Illinois waters.

INTRODUCTION: Differences in growth among genetically distinct muskellunge stocks and populations may be important in determining the most appropriate populations for use in management applications. Different stocks of muskellunge have evolved under different ecological conditions, and as a result, have likely acquired different performance characteristics. Koppleman and Philipp (1986) found that 9 populations of muskellunge were genetically grouped into stocks and could be related to major river drainages, suggesting the existence of separate stocks associated with major river drainages. It is likely that as muskellunge were isolated into major river drainages, they experienced different thermal histories. As these separate groups progressed through evolutionary time, natural selection acted on the groups, resulting in groups of fish that are genetically dissimilar, and likely physiologically and behaviorally different from one another (Altukhov 1981; MacLean and Evans 1981; Begg et al. 1999a; Begg and Waldman 1999). These physiological differences could affect growth rates at various temperatures and will affect the appropriateness of a population for developing various Illinois fisheries.

Numerous studies have used physiological and behavioral traits for both discriminating among stocks and for demonstrating adaptation of stocks to different environments. Swimbladder gas retention was shown to be significantly different among two populations of lake trout *Salvelinus namaycush* (Ihssen and Tait 1974) and MacLean et al. (1981) demonstrated that significant differences in survival existed between populations of lake trout. Growth, an ecologically and economically important characteristic of cultured recreational fishes, can be influenced by both the environment and genetics. Luey and Adelman (1984) found significant differences in growth among groups of rainbow smelt *Osmerus mordax* sampled from three zones in Lake Michigan. These findings were consistent with previous genetic evidence suggesting three distinct stocks of rainbow smelt. A study of life history and electrophoretic characteristics of five allopatric stocks of lake whitefish *Coregonus clupeaformis* found differences in diet, growth rate, movement patterns, and fecundity (Ihssen et al. 1981). Considerable behavioral and physiological differences can be observed among stocks of fish perceived to be very similar and it is important to incorporate this knowledge of stocks into management plans. Differences in physiological and behavioral traits, such as growth, may exist for different stocks of muskellunge and it is important to work towards accounting for these differences in future management plans.

Previous work has compared food consumption, metabolism, and growth among populations of muskellunge (Clapp and Wahl 1996). These laboratory studies evaluated six populations of young-of-year (YOY) muskellunge (Kentucky’s Cave Run Lake, Minnesota’s Leech Lake, New York’s Lake Chautauqua, Ohio’s Clear Fork Lake, St. Lawrence River, and Wisconsin’s Minocqua Chain) at varying temperatures (5 – 27.5°C). The populations investigated represented muskellunge from each of the three identified muskellunge stocks, the Ohio River drainage stock, the Upper Mississippi River drainage stock, and the Great Lakes drainage stock (Table 1). Differences in growth and food consumption of YOY among populations were observed at higher temperatures (15 – 27.5°C). However, no significant differences in metabolism were observed at any temperature. Although results of these laboratory experiments showed bioenergetic differences among populations of muskellunge, they could not be explained solely in terms of thermal adaptation or established genetic groupings.

Thermal adaptation is the concept that genetic variation in physiological rates (e.g. growth rates, metabolic rates) represents local population adaptation to native environments (Yamahira and Conover 2002). The theory predicts that physiological rates operate most efficiently (e.g. highest growth rates) at the temperatures most commonly experienced in the native environment (Levinton 1983; Levinton and Monahan 1983; Lonsdale and Levinton 1985). Despite the failure of the current muskellunge data (Clapp and Wahl 1996) to conform to this model, studies of marine invertebrates (Levinton 1983; Levinton and Monahan 1983), crustaceans (Lonsdale and Levinton 1985), and fish (Galarowicz and Wahl 2003) have supported the idea of thermal adaptation. Based on the model of thermal adaptation, it would be expected that muskellunge from higher latitudes (Minnesota's Leech Lake and Wisconsin's Minocqua populations) would exhibit higher food consumption, greater conversion efficiency, and faster growth at lower temperatures than muskellunge from lower latitudes (Kentucky's Cave Run Lake population, for example) and conversely, muskellunge from lower latitudes were expected to exhibit greater rates and efficiency at higher temperatures. These relationships, although observed in a few instances, were not consistent in previous work with muskellunge (Clapp and Wahl 1996).

An alternative to the thermal adaptation model of latitudinal compensation focuses on differences in length of the growing season across latitudes (Conover and Present 1990; Yamahira and Conover 2002). There exists a latitudinal gradient with regards to length of the growing season, with lower latitudes having longer growing seasons than higher latitudes. In this model, termed countergradient variation, growth of both high and low latitude individuals occurs over the same range of temperatures, yet the growth rates at each temperature varies with latitude, resulting in similar sizes at the end of the growing season (Yamahira and Conover 2002). Some studies have found that individuals from northern latitude populations actually have a larger biomass at the end of the growing season than do individuals from southern latitude populations (Conover and Present 1990). A growing body of literature for several fishes supports the concept of countergradient variation in physiological rates, specifically growth rates (Conover and Present 1990; Nicieza et al. 1994; Schultz et al. 1996; Conover et al. 1997; DiMichele and Westerman 1997; Jonassen et al. 2000). In common environment experiments, such as Clapp and Wahl (1996), it would be expected that across all temperatures comprising the growing season, muskellunge from the northern populations would exhibit higher food consumption, greater conversion efficiency, and faster growth than muskellunge from lower latitudes. Although not statistically significant, muskellunge from the Upper Mississippi River drainage stock had slightly higher consumption, growth, and metabolic rates from 15 – 25 C than muskellunge from the Ohio River drainage stock (Clapp and Wahl 1996). This pattern, although not significant, warrants further investigation.

In this study, we investigate population differentiation of muskellunge in the field from the YOY stage to adults. Long-term growth of muskellunge will be evaluated in pond and lake experiments. Identifying growth differences among muskellunge populations at these scales is important in defining these populations and in determining the most appropriate populations for specific management applications. Populations may vary in long-term growth, age-at-maturity, and maximum size. In this job, we assessed variation in growth among different YOY muskellunge populations and continued assessment of growth differences among previously introduced populations of muskellunge.

PROCEDURES: In the first year of the study, as described in the previous annual report, we began by comparing growth between two different stocks and populations of muskellunge in Lake Mingo, Vermillion County, Illinois (Table 2). Comparisons of growth among these muskellunge stocks and populations were continued. During 2003, additional introductions were conducted in Lake Mingo, as well as in Pierce Lake, Winnebago County, and Forbes Lake, Marion County (Figure 1, Table 3). These reservoirs represent the climatic variation associated with latitude that exists throughout Illinois. Choice of stocks was dependent on availability of fish from each of the populations. Future segments of the project will include these same as well as additional stocks and populations.

Muskellunge from the Upper Mississippi River drainage stock included the Leech Lake population obtained from the Minnesota Department of Natural Resources and the Minocqua Chain population obtained from the Wisconsin Department of Natural Resources. Muskellunge from the Ohio River drainage stock included the Lake Chautauqua population obtained from the New York State Department of Environmental Conservation and the Clear Fork Lake population obtained from the Ohio Department of Natural Resources. The Illinois population is the F1 progeny from North Spring Lake and was obtained from the Jake Wolf Memorial Fish Hatchery, Illinois Department of Natural Resources. Attempts were made to stock as similar of sizes and condition of fish as possible. Subsamples of each stock were held in three 3-m deep predator-free cages (N=15/cage) for 48-hrs to monitor mortality associated with transport and stocking stress. Muskellunge from each population were stocked at rates between 1.0 – 8.2 fish per hectare. A subsample of each population was measured in length (nearest mm) and weighed (nearest g) prior to each stocking (Table 3). Each fish was given an identifying complete pelvic fin clip (individual or in combination) and freeze cauterization of the wound for later identification of the stock (Boxrucker 1982).

To determine growth rates, nighttime pulse DC boat-electrofishing sampling was performed from October through December 2003 and from March through May 2004 on all study reservoirs. Length (nearest mm) and weight (nearest g) measurements were taken on sampled muskellunge. The pelvic fin clip was used to identify the stock and population and an upper caudal fin clip was used to conduct a Schnabel population estimate within each sampling season (Ricker 1975). Scales were taken from muskellunge sampled from Lake Mingo in order to determine age class (herein described as 2002 Year Class and 2003 Year Class). Upon capture, muskellunge from the 2002 Year Class in Lake Mingo were implanted with a Passive Integrated Transponder (PIT) tag prior to release to aid in future identification. Daily temperatures were recorded using a thermograph placed at 1-m depth to assess the role of temperature in influencing growth rates of different stocks and populations. These data were used to determine mean daily growth rates (g/d) and mean relative growth rates (standardizing by starting weight, g/g/d) among the stocks of muskellunge in the study reservoirs.

In addition to the evaluation of growth among muskellunge stocks in reservoirs, we conducted a pond experiment to evaluate growth among stocks in a more controlled environment. Advantages of this approach include greater precision via increased sample sizes, individual fish growth measurements, and replication by means of using several ponds. Three 0.4-ha experimental ponds at the Sam Parr Biological Station, Kinmundy, Illinois, were used for this experiment. Muskellunge from the Upper Mississippi River drainage stock (Leech Lake population), the Ohio River drainage stock (Cave Run Lake population), and the North Spring Lake, Illinois progeny (obtained from the Jake Wolf Memorial Fish Hatchery, IDNR) were stocked into the experimental ponds in fall 2002 and drained in spring and fall of 2003 (Table 4).

This experiment will herein be referred to as the 2002 Pond Experiment. The pond experiment was repeated with similar muskellunge stocks and populations introduced into experimental ponds during fall 2003 (Table 5) and will herein be referred to as the 2003 Pond Experiment. Thirty-three individuals from all populations were stocked into each of the three ponds (total N = 99 fish/pond). Immediately prior to stocking, each fish was anesthetized and implanted with a passive integrated transponder (PIT) tag in a similar manner as described by Harvey and Campbell (1989). Following the tagging, each fish was measured in length (nearest mm) and weighed (nearest g) and allowed to recover prior to being stocked into one of the ponds (Table 5). Hourly temperature readings were recorded using thermographs placed at 1-m depth and on the bottom.

Experimental ponds were drained in April 2004. Muskellunge were collected and identified by the PIT tag. All fish were measured in length (nearest mm) and weight (nearest g) and placed back into one of three 1-acre (0.4-ha) experimental ponds for future evaluations. These data were used to determine mean daily growth rates and mean relative growth rates among the stocks of muskellunge in experimental ponds. Results of the reservoir and pond evaluations will provide insight as to the fastest growing population in Illinois.

FINDINGS: Two populations, Cave Run Lake (Ohio River drainage stock) and Illinois (Table 1), stocked into Lake Mingo during fall 2002 were monitored during fall 2003 (Table 2). Unequal numbers were stocked due to limited availability of Cave Run Lake muskellunge. Mean initial lengths of the two populations were similar, but mean initial weights were higher for the Illinois population than the Cave Run Lake population (Table 2). The fall 2003 sampling showed that the Illinois muskellunge had a significantly higher mean daily growth rate than the Ohio River drainage stock one year post stocking (Figure 2, Table 6). Conversely, the Ohio River drainage stock muskellunge exhibited a significantly higher mean relative growth rate than the Illinois muskellunge over the same period (Figure 2, Table 6). A year and a half after stocking, the Illinois muskellunge maintained a slightly greater mean body length (Figure 3, Top Panel) and a larger body weight (Figure 3, Bottom Panel) than the Ohio River drainage stock.

In fall 2003, three populations were introduced in Pierce Lake (Table 3). Unequal numbers were stocked (Leech Lake N = 100, Lake Chautauqua N = 234, and Illinois N = 500) due to limited availability of the populations. Some differences in stocking sizes existed with the Upper Mississippi River drainage stock having the lowest mean initial lengths and weights and the Illinois population having the highest mean initial lengths and weights (Table 3). Spring 2004 sampling (Table 7) showed significant differences in mean daily growth rates (ANOVA, $P < 0.0001$) and mean relative growth rates (ANOVA, $P = 0.0003$) among populations. Illinois muskellunge had a significantly higher mean daily growth rate (g/d) than the Ohio River drainage stock (Figure 4; Tukey, $P = 0.0005$), which had a significantly higher mean daily growth rate than the Upper Mississippi River drainage stock (Tukey, $P = 0.0018$). The Illinois population and the Ohio River drainage stock had similar mean relative growth rates (g/g/d) (Figure 4; Tukey, $P = 0.91$), but both had significantly higher mean relative growth rates than the Upper Mississippi River drainage stock (Tukey, $P = 0.0004$, $P = 0.0003$, respectively).

Three populations of muskellunge were introduced in Lake Mingo in fall 2003 (Table 3). Unequal numbers were stocked (Leech Lake N = 285, Clear Fork Lake N = 288, and Illinois N = 500) due to limited availability of the populations. Stocking sizes were similar, with the Illinois population having only slightly higher mean initial lengths and weights (Table 3). Three 3-m deep predator-free mortality cages were monitored for 48-hrs post stocking to evaluate stocking mortality of each population. The Upper Mississippi River drainage stock and the Ohio River drainage stock exhibited 0% mortality and the Illinois population exhibited 13% mortality. This mortality was attributed to the warmer water temperatures when the Illinois muskellunge were stocked in late August (Mather and Wahl 1989; Wahl 1999). Subsequent analyses of survival will be adjusted to account for this initial mortality. Spring 2004 sampling (Table 8) showed significant differences in mean daily growth rates among populations (Figure 5; ANOVA, $P = 0.002$) but no significant differences in mean relative growth rates (ANOVA, $P = 0.35$). Illinois muskellunge had a significantly higher mean daily growth rate than the Upper Mississippi River drainage and Ohio River drainage stocks (Figure 5; Tukey, $P = 0.02$, $P = 0.007$, respectively). Mean daily growth rates for muskellunge from the Upper Mississippi River drainage did not differ from the Ohio River drainage muskellunge (Figure 5; Tukey, $P = 0.98$).

Two populations of muskellunge were introduced in Forbes Lake in fall 2003 (Table 3). Unequal numbers were stocked (Minocqua Chain $N = 217$ and Illinois $N = 500$) due to limited availability of the populations. Stocking sizes were similar among populations (Table 3). Three 3-m deep predator-free mortality cages were monitored for 48-hrs post stocking to evaluate stocking mortality of each population. The Upper Mississippi River drainage stock exhibited 27% mortality and the Illinois population exhibited 20% mortality. This mortality was attributed to the warmer water temperatures found at this latitude during late August and early September (Mather and Wahl 1989; Wahl 1999). Subsequent analyses of survival will be adjusted to account for these initial mortalities. No muskellunge were captured during spring 2004 sampling despite 11-hrs of electrofishing effort. Therefore, no results of growth are reported for the period from stocking until spring 2004.

Three populations were stocked in equal numbers into three 0.4-ha experimental ponds at the Sam Parr Biological Station in fall 2002 as described in the previous annual report. The ponds were drained in mid April 2003 and again in early October 2003 (Table 4). At draining in spring 2003, no Leech lake muskellunge were recovered from any of the ponds. No significant difference in mean daily growth rate (g/d) was observed between the Illinois population and the Ohio River drainage stock over the 6-mo period; however, a significant difference in mean relative growth rate (g/g/d) was observed between these two populations (Table 9). The Ohio River drainage stock had a three-fold higher mean relative growth rate than the Illinois muskellunge (Figure 6, Top Panel). Ponds were drained in fall 2003 to assess growth after one year. No significant difference in mean daily growth rate was detected between the two stocks; however, a significant difference in mean relative growth rate was observed (Table 10). The Ohio River drainage stock had almost a four-fold higher mean relative growth rate than the Illinois muskellunge (Figure 6, Bottom Panel).

The pond experiment was repeated in fall 2003. Three populations of muskellunge were stocked in equal numbers into three 0.4-ha experimental ponds at the Sam Parr Biological Station in late October 2003. The Upper Mississippi River drainage stock is represented by the Leech Lake population, the Ohio River drainage stock is represented by the Cave Run Lake population, and the Illinois population is the progeny of the North Spring Lake. The initial mean lengths and weights were not significantly different between the Upper Mississippi River drainage stock and the Ohio River drainage stock muskellunge (Table 5). The initial mean length and weight for the Illinois muskellunge was slightly higher (Table 5). Ponds were visually monitored for 48-hrs post stocking to assess mortality due to PIT tagging and handling. No short-term mortality was observed. Ponds were drained in mid April 2004. Significant differences in mean daily growth rates (ANOVA, $P < 0.0001$) and mean relative growth rates

(ANOVA, $P < 0.0001$) among populations were observed for this 6-mo period (Table 11). The Illinois population did not differ from the Ohio River drainage stock with regards to mean daily growth rate (Figure 7; Tukey, $P = 0.98$); however, both populations exhibited significantly higher mean daily growth rates than the Upper Mississippi River drainage stock (Figure 7; Tukey, $P < 0.0001$, $P < 0.0001$, respectively). The Ohio River drainage stock had a significantly higher mean relative growth rate than both the Illinois population and the Upper Mississippi River drainage stock (Figure 7; Tukey, $P < 0.0001$, $P < 0.0001$, respectively). The Upper Mississippi River drainage stock muskellunge exhibited a slightly higher mean relative growth rate than the Illinois population (Figure 7; Tukey, $P = 0.02$).

RECOMMENDATIONS: Any long-term differences among muskellunge populations we observe in reservoir and pond experiments will have important implications for conservation of native muskellunge populations, as well as for introduction of muskellunge into waters where they do not naturally occur. When muskellunge are introduced in areas where they have not previously occurred, such as Illinois impoundments, knowledge of population differentiation will be useful in planning stocking programs. Growth differences we observed among YOY and juvenile muskellunge during the first two years of this study can influence initial survival; both by loss to predation (Wahl and Stein 1989) and loss due to over-winter mortality (Bevelhimer et al. 1985; Carline et al. 1986). We have found initial growth differences among populations of muskellunge that will need to continue to be monitored as fish grow into adults.

In both the reservoir and pond experiments, the Upper Mississippi River drainage stock has thus far consistently exhibited the lowest mean daily growth rate (g/d) and lowest mean relative growth rate (g/g/d). The Illinois population typically exhibits the highest mean daily growth. When standardized for initial starting size by calculating the mean relative growth, the Illinois population usually still has the highest growth rates. The Ohio River drainage stock is exhibiting growth rates similar to those of the Illinois population. Examining the longest data set thus far, the 2002 Year Class in Lake Mingo, we see that the growth rates differ very little between the Illinois and the Ohio River drainage stock muskellunge (Figure 2, Figure 3).

Thus far in this study, the thermal adaptation concept seems to explain growth of muskellunge stocks more closely than the countergradient variation theory. The climate of the Ohio River drainage is likely more similar to Illinois than is the climate of the Upper Mississippi River drainage. Under the assumptions of the thermal adaptation concept, it would be predicted that the Ohio River drainage stock would exhibit higher growth rates in Illinois than the Upper Mississippi River drainage stock. The North Spring Lake population used for broodstock in Illinois was first established in the early 1980's and has subsequently been stocked yearly with muskellunge from throughout the native range of the species. The actual progeny of broodstock from any particular year results in an unknown-origin population, or possibly, a mixed-origin population. Future years of data will be needed, with as similar of initial lengths and weights as possible among stocks and populations, to be able to determine if the current trend of faster growth of the Illinois population is consistent.

Further fall and spring monitoring of the study reservoirs will be conducted, as well as additional introductions of the various stocks into the reservoirs for the purpose of growth evaluation. The three 0.4-ha experimental ponds will be drained in fall 2004 to evaluate growth of the muskellunge stocks in the experiment. In fall 2004, another trial of the pond experiment will be initiated with additional populations of muskellunge from each of the stocks. The results obtained from these initial two years will be combined with data from future years to identify differences among genetic stocks of muskellunge and to develop guidelines for future stockings that maximize growth in impoundments throughout Illinois.

Job 101.2. Evaluating survival of different stocks of muskellunge.

OBJECTIVE: To determine differences in survival among various stocks and populations of muskellunge in Illinois waters.

INTRODUCTION: In addition to growth, survival differences among genetically distinct muskellunge stocks and populations may be important in determining the most appropriate populations for use in management applications. Survival and other population characteristics is the consequence of life history modes to which stocks have evolved (Begg et al. 1999b). Physiological differences among stocks could affect survival rates at various temperatures and will affect the value of a population for stocking in various waters throughout Illinois.

Numerous studies have investigated differences in survival among stocks, however most of this work has been done with salmonids. Significant differences in survival were found between hatchery reared and wild steelhead trout *Salmo gairdneri* in stream and pond evaluations; however outcomes varied between systems (Reisenbichler and McIntyre 1977). Genetic origin has been shown to influence survival among stockings of lake trout *Salvelinus namaycush* in two lakes in Ontario (MacLean et al. 1981). In comparisons of survival of northern largemouth bass *Micropterus salmoides salmoides*, Florida largemouth bass *Micropterus salmoides floridanus,* and their F1 hybrids in central Illinois, the native northern largemouth bass was shown to have the highest survival rates (Philipp and Whitt 1991). Further work suggested significant survival differences between stocks of northern largemouth bass from two different river drainages within Illinois when both were stocked in northern and southern Illinois (Philipp and Claussen 1995). These studies suggest that geographic origin (stock) can have a substantial influence on survival in a given region.

Limited work has been done evaluating survival differences among muskellunge stocks and populations. In Minnesota, performance of four native muskellunge populations of the Mississippi River drainage stock showed similar survival, with the exception of the lower survival of the Shoepack population (Younk and Strand 1992). Performance differences were also evaluated among 5 local populations in Wisconsin and compared to the performance of the Leech Lake, Minnesota population (Margenau and Hanson 1996; Margenau and Hanson 1997). Short-term (<60 d) survival was higher for the Mud/Callahan Lake population compared to the other four Wisconsin populations (Maragenau and Hanson 1996). The remaining four populations all expressed similar short-term survival. Results showed that the Leech Lake population could be introduced into Wisconsin lakes and survive, however, there was no distinct advantage over the Wisconsin lake muskellunge populations (Margenau and Hanson 1997). All of these studies examined survival among populations of muskellunge from one stock, the Upper Mississippi River drainage stock. There exists a need to evaluate the survival differences among the three genetic stocks of muskellunge, the Ohio River drainage stock, the Upper Mississippi River drainage stock, and the Great Lakes drainage stock (Table 1). Many muskellunge fisheries, including those in Illinois, are sustained by stockings of muskellunge into waters where the species has been extirpated or for new introductions. In these scenarios, it would be beneficial to know which stock and populations have the highest survival in the thermal regime of the region to be stocked.

In this job, we are investigating population and stock differentiation in terms of survival for muskellunge in the field. Long-term survival of muskellunge is being evaluated in reservoir and pond experiments. Identifying survival differences among muskellunge populations at these scales is important in defining these populations and in determining the most appropriate populations for specific management applications. In this job, we continued assessment of variation in survival among different YOY and juvenile muskellunge populations. Future work will monitor survival of these populations through adults.

PROCEDURES: In the first year of the study, as described in the previous annual report, we began by comparing survival between two different stocks and populations of muskellunge in Lake Mingo, Vermillion County, Illinois (Table 2). Comparisons of survival among muskellunge stocks and populations were continued this year with additional introductions into Mingo Lake, as well as Pierce Lake, Winnebago County, and Forbes Lake, Marion County (Figure 1, Table 3). These reservoirs represent the latitudinal climatic variation that exists throughout Illinois. Choice of populations was dependent upon availability of fish from each of the stocks. Future segments of the project will include these same as well as additional stocks and populations.

As described in Job 101.1, we stocked muskellunge from the Upper Mississippi River drainage stock, the Ohio River drainage stock, and the Illinois population into three study reservoirs in fall 2003 (Table 3). Muskellunge were stocked at a large fingerling size to increase initial survival across all populations as determined in previous studies (Carline et al. 1986; Szendrey and Wahl 1996; McKeown et al. 1999). Stocked fish were also reared under as similar conditions and feeding regimes as possible so as to eliminate any indirect biases on survival or vulnerability to predation (Szendrey and Wahl 1995). Subsamples of each stock were held in three 3-m deep predator-free cages (N=15/cage) for 48-hrs to monitor mortality associated with transport and stocking stress. Muskellunge from each population were stocked at rates between 1.0 – 8.2 fish per hectare (Table 3). Each fish was given an identifying complete pelvic fin clip (individual or in combination) and freeze cauterization of the wound for later identification of the stock. Previous work has suggested that removal of any single paired fin is equally detrimental to short-term survival (3-mo) and the loss of a pelvic fin is less detrimental than loss of a pectoral fin over the long term (McNeil and Crossman 1979). To determine survival, nighttime pulse DC boat-electrofishing sampling was performed from October through December 2003 and from March through May 2004 on all study reservoirs. Electrofishing catch-per-unit-effort (CPUE) and Schnabel population estimates (Ricker 1975) were used to assess survival differences among stocks.

In addition to the evaluation of survival differences among muskellunge stocks in reservoirs, we conducted a pond experiment to evaluate survival among stocks in a more controlled environment. Advantages of this approach include the ability of obtaining a direct measurement of survival via pond draining. Three 0.4-ha experimental ponds at the Sam Parr Biological Station, Kinmundy, Illinois, were used for this experiment. As described in the previous annual report, muskellunge from the Upper Mississippi River drainage stock, the Ohio River drainage stock, and the Illinois population were stocked into the experimental ponds in fall 2002 and were drained in spring 2003 and again in fall 2003 (Table 4). The pond experiment was repeated with the same muskellunge stocks and populations stocked into experimental ponds in October 2003 (Table 5). Thirty-three individuals from all populations were stocked into each of the three ponds (total N = 99 fish/pond).

Experimental ponds were drained in April 2004. Muskellunge were collected and population identified by the PIT tag. All surviving fish were placed back into one of three 0.4-ha experimental ponds for future evaluations. These data were used to determine survival among the stocks of muskellunge in experimental ponds using a maximum likelihood estimation approach. Results of the reservoir and pond evaluations will provide insight as to the best surviving population in Illinois.

FINDINGS: Two populations, Cave Run Lake (Ohio River drainage stock) and Illinois (Table 1), were stocked into Lake Mingo during the fall 2002 (Table 2). Three 3-m deep predator-free mortality cages were monitored for 48-hrs post stocking to evaluate stocking mortality of each population. Both populations showed 0% mortality after the 48-hr monitoring period. Mark-recapture sampling during fall 2003 was used to determine a Schnabel population estimate. CPUE was also calculated for each sampling event. Schnabel population estimates were lower for the Ohio River drainage muskellunge (N = 48) than for the Illinois population (N = 94) (Table 12). Survival one year post stocking is estimated at 28% for the Ohio River drainage stock and 24% for the Illinois population (Table 12). Adjusted CPUE was calculated by adjusting CPUE to account for unequal stocking numbers among stocks and populations. During fall 2003, the adjusted CPUE increased over time for both populations, suggesting increasing capture efficiency as water temperatures become cooler (Figure 8). The adjusted CPUE was higher for the Ohio River drainage stock muskellunge on all sampling dates except one, suggesting slightly higher survival through the first year of the Ohio River drainage stock than the Illinois population.

In fall 2003, three populations of muskellunge were introduced in Pierce Lake (Table 3). Sampling during spring 2004 was used to determine a Schnabel population estimate. Adjusted CPUE was also calculated for each sampling event. Schnabel population estimates predict a point estimate of N = 58 for the Ohio River drainage stock and N = 5 for the Illinois population (Table 13). No population estimates were calculated for the Upper Mississippi River drainage stock due to low number of recaptures (Table 13). Survival over the 6-mo interval from stocking through spring 2004 was estimated to be 25% for the Ohio River drainage stock and 1% for the Illinois population (Table 13). Adjusted CPUE remained fairly constant for all populations over the duration of the spring sampling season (Figure 9). With the exception of the first two sampling dates, the Ohio River drainage stock had the highest adjusted CPUE suggesting higher survival 6-mo after stocking than the Upper Mississippi River drainage stock and the Illinois population (Figure 9).

Three populations of muskellunge were introduced in Lake Mingo in fall 2003 (Table 3). Three 3-m deep predator-free mortality cages were monitored for 48-hrs post stocking to evaluate stocking mortality of each population. The Upper Mississippi River drainage stock and the Ohio River drainage stock exhibited 0% mortality and the Illinois population exhibited 13% mortality. This mortality was attributed to the warmer water temperatures when the Illinois muskellunge were stocked in late August (Mather and Wahl 1989; Wahl 1999). Subsequent analyses of survival will be adjusted to account for this initial mortality. Sampling in spring 2004 was used to determine a Schnabel population estimate and adjusted CPUE was calculated for each sampling event. Schnabel population estimates provide a point estimate of N = 40 for the Upper Mississippi River drainage stock, N = 85 for the Ohio River drainage stock, and N = 59 for the Illinois population (Table 14). Survival over the 6-mo period from stocking through spring 2004 was 14% for the Upper Mississippi River drainage stock, 30% for the Ohio River drainage stock, and 14% for the Illinois population (Table 14). Adjusted CPUE decreased over the duration of the sampling season, suggesting higher capture efficiencies of all stocks during the early spring when water temperatures were cooler (Figure 10). There was no consistent trend in adjusted CPUE over the sampling season to indicate reliable survival differences. Over most dates, however, the Upper Mississippi River drainage stock exhibited low or the lowest adjusted CPUE, suggesting poorer survival for this stock (Figure 10).

Two populations of muskellunge were introduced in Forbes Lake in fall 2003 (Table 3). Three 3-m deep predator-free mortality cages were monitored for 48-hrs post stocking to evaluate stocking mortality of each population. The Upper Mississippi River drainage stock exhibited 27% mortality and the Illinois population exhibited 20% mortality. This mortality was attributed to the warmer water temperatures found at this latitude during late August and early September (Mather and Wahl 1989; Wahl 1999). No muskellunge were captured during the spring 2004 sampling season despite 11-hrs of electrofishing effort. As a result, no survival estimates are reported for the period from stocking through spring 2004.

Three populations were stocked in equal numbers into three 0.4-ha experimental ponds at the Sam Parr Biological Station during fall 2002 as described in the previous annual report. The ponds were drained in mid April 2003 and again in early October 2003 (Table 4). At draining in spring 2003, no Upper Mississippi River drainage stock muskellunge were recovered from any of the ponds. Survival was highest for the Illinois muskellunge over the 6-mo period from stocking through the spring 2003 draining (Figure 11, Top Panel) and for the 1-yr period from stocking through fall 2003 draining (Figure 11, Bottom Panel).

A pond experiment was also conducted in fall 2003. Three populations of muskellunge were stocked in equal numbers into three 0.4-ha experimental ponds at the Sam Parr Biological Station between October 25 and October 30, 2003 (Table 5). Ponds were visually monitored for 48-hrs post stocking to assess mortality due to PIT tagging and handling. No short-term mortality was observed. Ponds were drained in mid April 2004. No significant survival differences among stocks were observed for the 6-mo period from stocking through spring 2004 draining (Figure 12). All three muskellunge stocks had survival rates from 70 – 80%.

RECOMMENDATIONS: Any long-term differences in survival among muskellunge populations will have important implications for conservation and stocking of muskellunge. Survival differences we observed among YOY and juvenile muskellunge during the first two years of this study can influence the success and cost-effectiveness of a muskellunge stocking program (Margenau 1992). We have found initial survival differences among populations of muskellunge that will need to continue to be monitored as fish grow into adults.

Initial impoundment results suggest the Ohio River drainage stock muskellunge have a survival advantage over the other muskellunge stocks. However, the pond experiment trials show the Illinois muskellunge to have a survival advantage over the Ohio River drainage and Upper Mississippi River drainage stocks. Analysis of the Lake Mingo 2002 Year Class of muskellunge stocked into the reservoir shows the Ohio River drainage stock to have a slight survival advantage after 1-yr over the Illinois population. Muskellunge of the Ohio River drainage stock appear to have higher 6-mo survival than the other populations in both Pierce and Mingo Lakes for the 2003 Year Class. The 2002 pond experiment shows the Illinois population to have higher survival rates than the Ohio River drainage stock muskellunge. It is important to note the stocking size differences between the Illinois population and the Ohio River drainage stock of muskellunge. There may be differential size-specific survival occurring in the 2002 pond experiment, a plausible cause for the complete mortality of the Upper Mississippi River drainage muskellunge. The 2003 pond experiment had more similar stocking sizes among the populations and 6-mos after stocking, no survival differences were observed among populations.

Further fall and spring monitoring of the study reservoirs will be conducted, as well as additional introductions of the various stocks into the three reservoirs for the purpose of evaluating survival differences among stocks. The three 0.4-ha experimental ponds will be drained in fall 2004 to evaluate survival of the muskellunge stocks in the experiment. In late October 2004, a third trial of the pond experiment will be initiated with additional populations of the major stocks. The results obtained from these past two and future years will be used to identify long-term differences in survival among genetic stocks of muskellunge.

Job 101.3. Analysis and reporting.

OBJECTIVE: To prepare annual and final reports summarizing information and develop guidelines for proper selection of muskellunge populations for stocking in Illinois impoundments.

PROCEDURES and FINDINGS: Data collected in Jobs 101.1 – 101.2 were analyzed to begin developing guidelines regarding appropriate muskellunge populations for stocking throughout Illinois. In future segments, recommendations will be made that will allow hatchery and management biologists to make decisions that will maximize benefits for the muskellunge program in Illinois.

LITERATURE CITED

Altukhov, Y.P. 1981. The stock concept from the viewpoint of population genetics. Canadian Journal of Fisheries and Aquatic Sciences 38: 1523-1538.

Begg, G.A., K.D. Friedland, and J.B. Pearce. 1999. Stock identification and its role in stock assessment and fisheries management: an overview. Fisheries Research 43: 1-8.

Begg, G.A. and J.R. Waldman. 1999. An holistic approach to fish stock identification. Fisheries Research 43: 35-44.

Bevelhimer, M.R., R.A. Stein, and R.F. Carline. 1985. Assessing significance of physiological differences among three esocids with a bioenergetics model. Canadian Journal of Fisheries and Aquatic Sciences 42: 57-69.

Boxrucker, J.C. 1982. Mass marking of fingerling largemouth bass by fin-clipping followed by freeze-cauterization of the wound. North American Journal of Fisheries Management 2: 94-96.

Carline, R.F., R.A. Stein, and L.M. Riley. 1986. Effects of size at stocking, season, largemouth bass predation, and forage abundance on survival of tiger muskellunge, Pages 151-167 *in* G. E. Hall, editor. Managing Muskies. American Fisheries Society, Special Publication 15, Bethesda, Maryland, USA.

Clapp, D.F. and D.H. Wahl. 1996. Comparison of food consumption, growth, and metabolism among muskellunge – an investigation of population differentiation. Transactions of the American Fisheries Society 125: 402-410.

Conover, D.O. and T.M.C. Present. 1990. Countergradient variation in growth rate: compensation for length of the growing season among Atlantic silversides from different latitudes. Oecologia 83: 316-324.

Conover, D.O., J.J. Brown, and A. Ehtisham. 1997. Countergradient variation in growth of young striped bass (*Morone saxatilis*) from different latitudes. Canadian Journal of Fisheries and Aquatic Sciences 54: 2401-2409.

DiMichele, L. and M.E. Westerman. 1997. Geographic variation in development rate between populations of the teleost *Fundulus heteroclitus*. Marine Biology 128: 1-7.

Galarowicz, T.L. and D.H. Wahl. 2003. Differences in growth, consumption, and metabolism among walleyes from different latitudes. Transactions of the American Fisheries Society 132:425-437.

Harvey, W.D. and D.L. Campbell. 1989. Retention of passive integrated transponder tags in largemouth bass brood fish. The Progressive Fish Culturist 51: 164-166.

Ihssen, P.E. and J.S. Tait. 1974. Genetic differences in retention of swimbladder gas between two populations of lake trout *Salvelinus namaycush*. Journal of the Fisheries Research Board of Canada 31:1351-1354.

Ihssen, P.E., D.O. Evans, W.J. Christie, J.A. Reckahn, and R.L. DesJardine. 1981. Life history, morphology, and electrophoretic characteristics of five allopatric stocks of lake whitefish *Coregonus clupeaformis* in the Great Lakes region. Canadian Journal of Fisheries and Aquatic Sciences 38: 1790-1807.

Jonassen, T.M., A.K. Imsland, R. Fitzgerald, S.W. Bonga, E.V. Ham, G. Naevdal, M.O. Stefansson, and S.O. Stefansson. 2000. Geographic variation in growth and food consumption efficiency of juvenile Atlantic halibut related to latitude. Journal of Fish Biology 56: 279-294.

Koppelman, J.B. and D.P. Philipp. 1986. Genetic applications in muskellunge management. Pages 111-121 *in* G.E. Hall, editor. Managing Muskies. American Fisheries Society, Special Publication 15, Bethesda, Maryland, USA.

Levinton, J.S. 1983. The latitudinal compensation hypothesis: growth data and a model of latitudinal growth differentiation based upon energy budgets. I. interspecific comparison of *Ophryotrocha* (Polychaeta: Dorvilleidae). Biological Bulletin (Woods Hole) 165: 686-698.

Levinton, J.S. and R.K. Monahan. 1983. The latitudinal compensation hypothesis: growth data and a model of latitudinal growth differentiation based upon energy budgets. II. intraspecific comparisons between subspecies of *Ophryotrocha puerilis* (Polychaeta: Dorvilleidae). Biological Bulletin (Woods Hole) 165: 699-707.

Lonsdale, D.J. and J.S. Levinton. 1985. Latitudinal differentiation in copepod growth: an adaptation to temperature. Ecology 66: 1397-1407.

Luey, J.E. and I.R. Adelman. 1984. Stock structure of rainbow smelt in western Lake Superior: population characteristics. Transactions of the American Fisheries Society 113:709-715.

MacLean, J.A. and D.O. Evans. 1981. The stock concept, discreteness of fish stocks, and fisheries management. Canadian Journal of Fisheries and Aquatic Sciences 38: 1889-1898.

MacLean, J.A., D.O. Evans, N.V. Martin, and R.L. DesJardine. 1981. Survival, growth, spawning distribution, and movements of introduced and native lake trout *Salvelinus namaycush* in two inland Ontario Lakes. Canadian Journal of Fisheries and Aquatic Sciences 38:1685-1700.

Margenau, T.L. 1992. Survival and cost-effectiveness of stocked fall fingerling and spring yearling muskellunge in Wisconsin. North American Journal of Fisheries Management 12: 484-493.

Margenau, T.L. and D.A. Hanson. 1997. Performance of Leech Lake, Minnesota, muskellunge in a Wisconsin Lake. Wisconsin Department of Natural Resources Research Report 175 175: 1-11.

Margenau, T.L. and D.A. Hanson. 1996. Survival and growth of stocked muskellunge: effects of genetic and environmental factors. Wisconsin Department of Natural Resources Research Report 172 172: 1-11.

Mather, M.E., and D.H. Wahl. 1989. Comparative mortality of three esocids due to stocking stressors. Canadian Journal of Fisheries and Aquatic Sciences 46: 214-217.

McKeown, P.E., J.L. Forney, and S.R. Mooradian. 1999. Effects of stocking size and rearing method on muskellunge survival in Chautauqua Lake, New York. North American Journal of Fisheries Management 19:249-257.

McNeil, F.I. and E.J. Crossman. 1979. Fin clips in the evaluation of stocking programs for muskellunge *Esox masquinongy*. Transactions of the American Fisheries Society 108:335-343.

Midwest Regional Climate Center (MRCC). 2004. http://mcc.sws.uiuc.edu/

National Oceanic and Atmospheric Administration (NOAA). 2004. http://www.noaa.gov/

New York State Climate Office (NYSCO). 2004. http://nysc.eas.cornell.edu/

Nicieza, A.G., F.G. Reyes-Gavilan, and F. Brana. 1994. Differentiation in juvenile growth and bimodality patterns between northern and southern populations of Atlantic salmon (*Salmo salar* L.). Canadian Journal of Zoology 72: 1603-1610.

Pennsylvania State Climatologist (PSC). 2004. http://pasc.met.psu.edu/PA_Climatologist/index.php

Philipp, D.P. and G.S. Whitt. 1991. Survival and growth of northern, Florida, and reciprocal F1 hybrid largemouth bass in Central Illinois. Transaction of the American Fisheries Society 120: 58-64.

Philipp, D.P. and J.E. Claussen. 1995. Fitness and performance differences between two stocks of largemouth bass from different river drainages within Illinois. American Fisheries Society Symposium 15: 236-243.

Reisenbichler, R.R., and J.D. McIntyre. 1977. Genetic differences in growth and survival of juvenile hatchery and wild steelhead trout *Salmo gairdneri*. Journal of the Fisheries Research Board of Canada 34: 123-128.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191. 382 pp.

Schultz, E.T., K.E. Reynolds, and D.O. Conover. 1996. Countergradient variation in growth among newly hatched *Fundulus heteroclitus*: geographic differences revealed by common-environment experiments. Functional Ecology 10: 366-374.

Szendrey, T.A. and D.H. Wahl. 1995. Effect of feeding experience on growth, vulnerability to predation, and survival of esocids. North American Journal of Fisheries Management 15:610-620.

Szendrey, T.A. and D.H. Wahl. 1996. Size-specific survival and growth of stocked muskellunge: effects of predation and prey availability. North American Journal of Fisheries Management 16: 395-402.

Wahl, D.H. and R.A. Stein. 1989. Comparative vulnerability of three esocids to largemouth bass *Micropterus salmoides* predation. Canadian Journal of Fisheries and Aquatic Sciences 46: 2095-2103.

Wahl, D.H. and R.A. Stein. 1991. Food consumption and growth of three esocids: field tests of a bioenergetics model. Transactions of the American Fisheries Society 120: 230-246.

Wahl, D.H. 1999. An ecological context for evaluating the factors influencing muskellunge stocking success. North American Journal of Fisheries Management 19: 238-248.

Weatherbase. 2004. http://www.weatherbase.com/

Yamahira, K. and D.O. Conover. 2002. Intra- vs. interspecific latitudinal variation in growth: adaptation to temperature or seasonality? Ecology 83: 1252-1262.

Younk, J.A. and R.F. Strand. 1992. Performance evaluation of four muskellunge *Esox masquinongy* strains in two Minnesota lakes. Minnesota Department of Natural Resources Section of Fisheries Investigational Report No. 418. pp 22.

Table 1. Sources of young-of-year muskellunge stocks used for evaluation of growth and survival. Kentucky, Ohio, Pennsylvania, and New York populations are from the Ohio River drainage (Ohio stock); Minnesota and Wisconsin populations are from the Upper Mississippi River drainage (Mississippi stock); St. Lawrence River muskellunge are from the Great Lakes drainage (Great Lakes stock). Cooling (CDD) and heating (HDD) degree days are calculated using a base temperature of 65° F, with 1961 - 1990 data from the National Oceanic and Atmospheric Administration, Midwest Climate Center, Pennsylvania State Climatologist, and the New York State Climate Office.

Population (abbreviation)	Source Water	Drainage (stock)	Latitude (north)	Cooling Degree Days (CDD)	Heating Degree Days (HDD)	Mean Annual Temp. (F)
Kentucky (KY)	Cave Run Lake	Ohio River	37° 35′	1154	4713	55.2
Ohio (OH)	Clear Fork Lake	Ohio River	39° 30′	703	6300	49.6
Pennsylvania (PA)	Pymatuning Reservoir	Ohio River	41° 30′	322	6934	47.4
New York (NY)	Lake Chautauqua	Ohio River	42° 07′	350	6279	49.4
St. Lawrence (SL)	St. Lawrence River	Great Lakes	42° 25′	551	6785	45.4
Wisconsin (WI)	Minocqua Chain	Mississippi River	45° 30′	215	9550	39.3
Minnesota (MN)	Leech Lake	Mississippi River	46° 35′	347	9495	39.9

Table 2. Stocking summary of muskellunge populations from the Ohio River drainage (OH) and North Spring Lake, IL progeny (IL) introduced in Lake Mingo during 2002. Total length (nearest mm) and weight (nearest g) were measured prior to stocking. Values in parentheses represent 95% confidence intervals.

Stock	Population	Stocking Date	Number of Fish	Number per Hectare	Mean Length (mm)	Mean Weight (g)
OH	Cave Run Lake, KY	October 30, 2002	171	2.4	315 (±7.5)	155 (±8.2)
IL	North Spring Lake, IL	October 24, 2002	400	5.6	336 (±5.6)	200 (±11.7)

Table 3. Stocking summary of muskellunge populations from the Upper Mississippi River drainage (MISS), Ohio River drainage (OH) and North Spring Lake, IL progeny (IL) introduced in Pierce Lake, Lake Mingo, and Forbes Lake during fall 2003. Total length (nearest mm) and weight (nearest g) were measured prior to stocking. Values in parentheses represent 95% confidence intervals.

Lake	Stock	Population	Stocking Date	Number of Fish	Number per Hectare	Mean Length (mm)	Mean Weight (g)
Pierce	MISS	Leech Lake, MN	November 7, 2003	100	1.6	197 (±5.0)	28 (±2.5)
	OH	Lake Chautauqua, NY	September 19, 2003	234	3.8	225 (±2.6)	44 (±1.7)
	IL	North Spring Lake, IL	August 29, 2003	500	8.2	258 (±3.3)	77 (±2.9)
Mingo	MISS	Leech Lake, MN	October 31, 2003	285	4.0	237 (±9.0)	60 (±7.7)
	OH	Clear Fork Lake, OH	September 4, 2003	288	4.0	227 (±2.5)	56 (±2.2)
	IL	North Spring Lake, IL	August 29, 2003	500	7.0	258 (±3.3)	77 (±2.9)
Forbes	MISS	Minocqua Chain, WI	September 9, 2003	217	1.0	248 (±4.8)	87 (±4.7)
	IL	North Spring Lake, IL	August 29, 2003	500	2.2	258 (±3.3)	77 (±2.9)

Table 4. Summary of initial and subsequent lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2002. Ponds were drained in April 2003 and again in October 2003. The Ohio River drainage stock is represented by the Kentucky Cave Run Lake population and the Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population. No Mississippi River drainage stock muskellunge were recovered in any of the ponds. Values in parentheses represent 95% confidence intervals.

Season	Ohio River Drainage	Mississippi River Drainage	Illinois
		Length (mm)	
Fall 2002	245 (± 5.9)	199 (± 3.3)	334 (± 4.9)
Spring 2003	284 (± 6.2)	-	361 (± 6.9)
Fall 2003	406 (± 11.3)	-	450 (± 9.3)
		Weight (g)	
Fall 2002	58 (± 3.8)	26 (± 2.1)	191 (± 8.7)
Spring 2003	92 (± 7.3)	-	229 (± 12.4)
Fall 2003	304 (± 31.4)	-	420 (± 28.4)

Table 5. Summary of initial and final lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2003 and drained in April 2004. The Ohio River drainage stock is represented by the Kentucky Cave Run Lake population and the Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population. Values in parentheses represent 95% confidence intervals.

Season	Ohio River Drainage	Mississippi River Drainage	Illinois
		Length (mm)	
Fall 2003	292 (± 4.5)	283 (± 7.2)	353 (± 3.9)
Spring 2004	338 (± 3.9)	323 (± 6.5)	386 (± 4.7)
		Weight (g)	
Fall 2003	96 (± 4.3)	98 (± 8.3)	190 (± 7.4)
Spring 2004	181 (± 7.4)	146 (± 9.6)	278 (± 11.1)

Table 6. Analysis of variance tests of the effect of stock on mean daily growth rates (g/d) and mean relative growth rates (g/g/d) of muskellunge populations from the Ohio River drainage and North Spring Lake, IL introduced in Lake Mingo during fall 2002. Growth is for the 1-yr interval from stocking through the following fall (October through December 2003). Sum of squares are Type III (SAS Institute V8).

Source of Variation	Degrees of Freedom	Sum of Squares	F	Pr > F
		Mean daily growth rate (g/d)		
Stock	1	2.470	6.26	0.02
Error	38	14.990		
		Mean relative growth rate (g/g/d)		
Stock	1	0.0000575	5.09	0.03
Error	38	0.000429		

Table 7. Summary of stocking and subsequent mean lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced in Pierce Lake during fall 2003. Spring sampling was conducted from March 10 through May 6, 2004. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the New York Lake Chautauqua population, and the Illinois muskellunge are North Spring Lake, IL progeny. Values in parentheses represent 95% confidence intervals.

Season	Mississippi River Drainage	Ohio River Drainage	Illinois
		Length (mm)	
Fall 2003	197 (±5.0)	225 (±2.6)	258 (±3.3)
Spring 2004	202 (±46.2)	284 (±9.4)	347 (±11.4)
		Weight (g)	
Fall 2003	28 (±2.5)	44 (±1.7)	77 (±2.9)
Spring 2004	28 (±21.7)	102 (±11.6)	191 (±30.8)

Table 8. Summary of stocking and subsequent mean lengths (nearest mm) and weights (nearest g) of three stocks of muskellunge introduced in Lake Mingo during fall 2003. Spring sampling was conducted from March 9 through May 5, 2004. The Upper Mississippi River drainage stock is represented by the Minnesota Leech Lake population, the Ohio River drainage stock is represented by the Ohio Clear Fork Lake population, and the Illinois muskellunge are North Spring Lake, IL progeny. Values in parentheses represent 95% confidence intervals.

Season	Mississippi River Drainage	Ohio River Drainage	Illinois
		Length (mm)	
Fall 2003	237 (±9.0)	227 (±2.5)	258 (±3.3)
Spring 2004	301 (±18.0)	306 (±9.7)	349 (±9.3)
		Weight (g)	
Fall 2003	60 (±7.7)	56 (±2.2)	77 (±2.9)
Spring 2004	105 (±22.2)	128 (±17.1)	191 (±18.8)

Table 9. Analysis of variance tests of the effects of stock and pond on mean daily growth rates (g/d) and mean relative growth rates (g/g/d) of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2002 and drained during April 2003. Sum of squares are Type III (SAS Institute V8).

Source of Variation	Degrees of Freedom	Sum of Squares	F	Pr > F
		Mean daily growth rate (g/d)		
Stock	1	0.005	0.42	0.52
Pond	2	0.745	34.54	<0.0001
Error	99	1.068		
		Mean relative growth rate (g/g/d)		
Stock	1	0.000092	121.79	<0.0001
Pond	2	0.000048	31.96	<0.0001
Error	99	0.000075		

Table 10. Analysis of variance tests of the effects of stock and pond on mean daily growth rates (g/d) and mean relative growth rates (g/g/d) of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2002. Growth is for the 1-yr interval from stocking in fall 2002 through draining in October 2003. Sum of squares are Type III (SAS Institute V8).

Source of Variation	Degrees of Freedom	Sum of Squares	F	Pr > F
		Mean daily growth rate (g/d)		
Stock	1	0.125	2.53	0.12
Pond	2	0.758	7.65	0.0011
Error	61	3.025		
		Mean relative growth rate (g/g/d)		
Stock	1	0.000589	252.05	<0.0001
Pond	2	0.000020	4.38	0.02
Error	61	0.000142		

Table 11. Analysis of variance tests of the effects of stock and pond on mean daily growth rates (g/d) and mean relative growth rates (g/g/d) of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2003 and drained during April 2004.
Sum of squares are Type III (SAS Institute V8).

Source of Variation	Degrees of Freedom	Sum of Squares	F	Pr > F
		Mean daily growth rate (g/d)		
Stock	2	2.593	107.28	<0.0001
Pond	2	0.419	17.32	<0.0001
Error	229	2.768		
		Mean relative growth rate (g/g/d)		
Stock	2	0.000326	150.36	<0.0001
Pond	2	0.000016	7.18	0.0009
Error	229	0.000248		

Table 12. Schnabel population estimates and relative survival of two stocks of muskellunge during the first year following stocking in Lake Mingo, fall 2002. Survival is calculated for the period from stocking through fall 2003 sampling (October 7 through December 4, 2003).

Stock	Total Number Captured	Total Number Recaptured	Schnabel Population Estimate		Survival (%)
			Point Estimate	95% C.I.	
OH	16	2	48	13-480	28
IL	24	2	94	26-945	24

Table 13. Schnabel population estimates and relative survival of three stocks of muskellunge introduced in Pierce Lake during fall 2003. Sampling was conducted from March 10 through May 6, 2004.

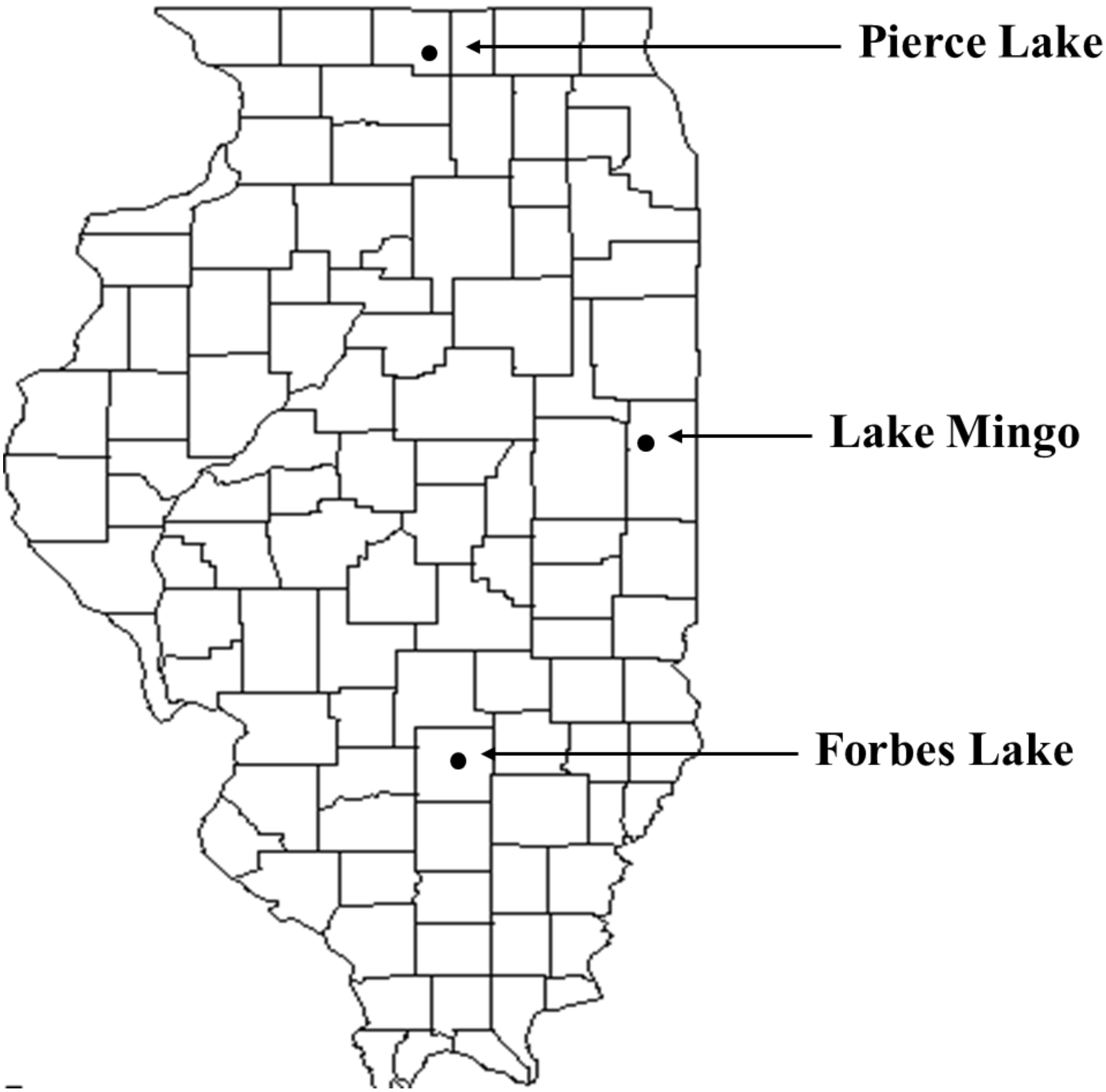
			Schnabel Population Estimate		
Stock	Total Number Captured	Total Number Recaptured	Point Estimate	95% C.I.	Survival (%)
MISS[a]	3	0	-	-	-
OH	13	1	58	10-580	25
IL	6	2	5	1-50	1

a. No point estimate available due to zero recaptures

Table 14. Schnabel population estimates and relative survival of three stocks of muskellunge introduced in Lake Mingo during fall 2003. Sampling was conducted from March 9 through May 5, 2004.

			Schnabel Population Estimate		
Stock	Total Number Captured	Total Number Recaptured	Point Estimate	95% C.I.	Survival (%)
MISS	12	1	40	7-400	14
OH	22	2	85	24-855	30
IL	30	5	59	25-185	14

Figure 1. Illinois reservoirs stocked for evaluation of growth and survival among muskellunge stocks.



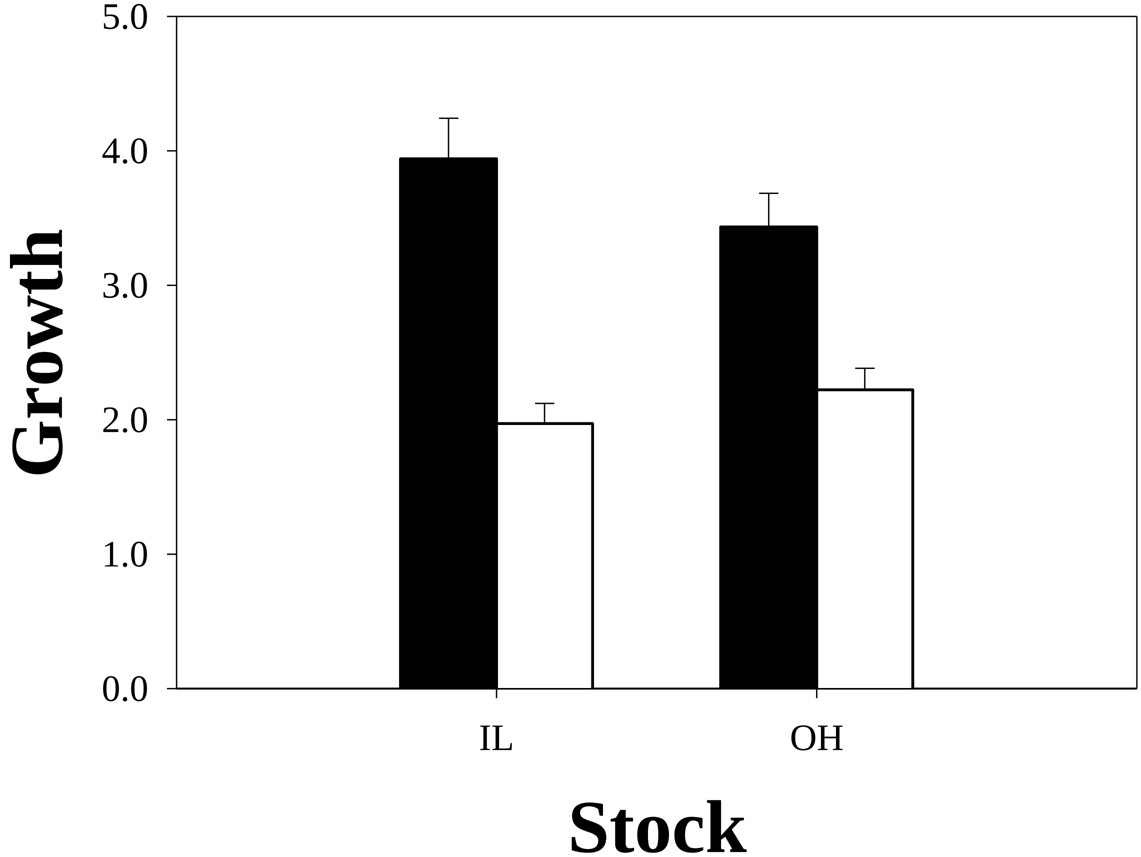


Figure 2. Mean daily growth rates (g/d, solid bars) and mean relative growth rates (g/g/d X 100, open bars) of muskellunge populations from the Ohio River drainage and North Spring Lake, IL introduced in Lake Mingo during fall 2002. Growth is from the time of stocking through the first fall (October through December 2003). The Ohio River drainage stock is represented by the Kentucky Cave Run Lake population and the Illinois muskellunge are North Spring Lake, IL progeny. Vertical lines represent 95% confidence limits.

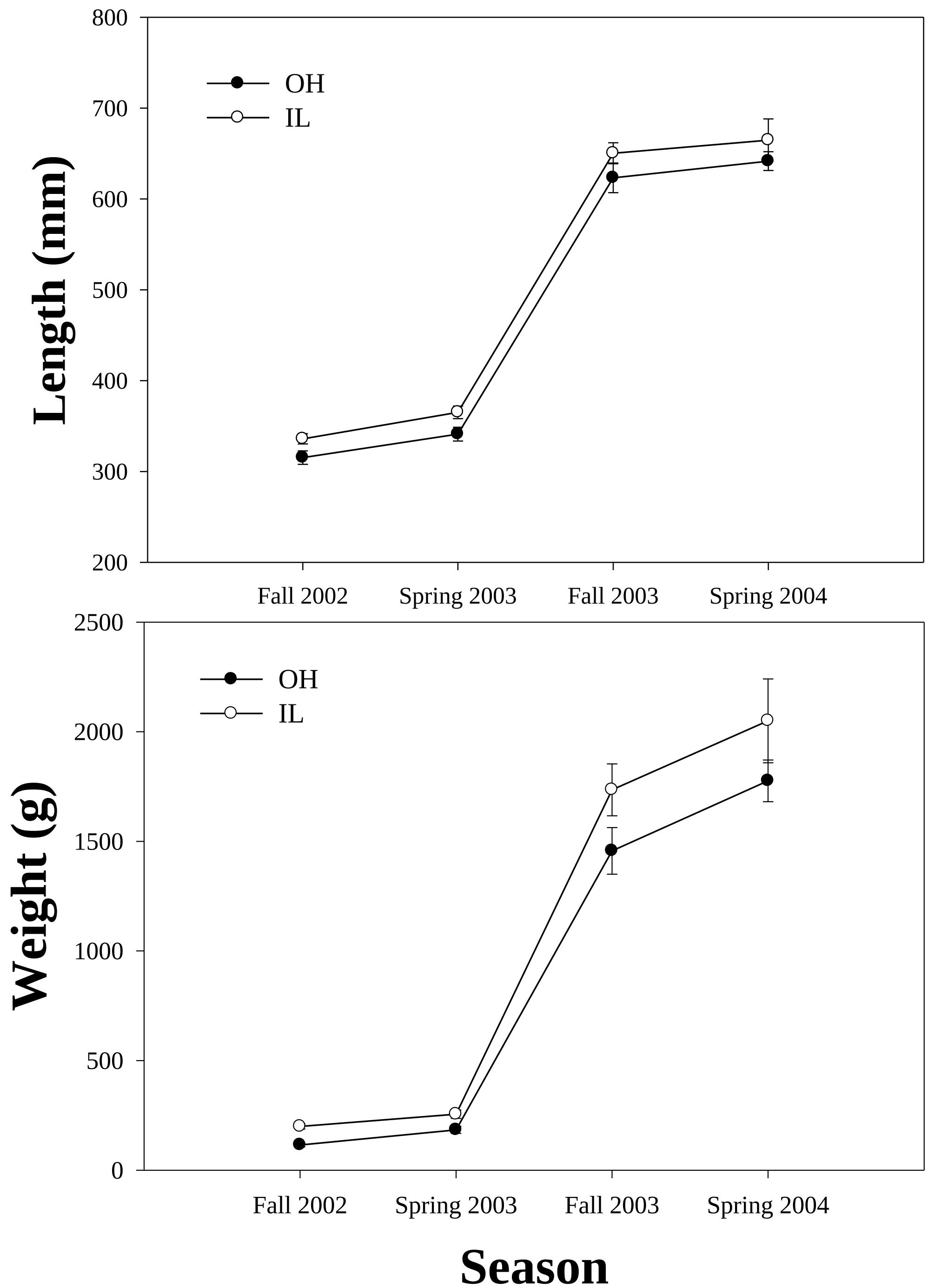


Figure 3. Stocking and subsequent sample mean lengths (nearest mm) and weights (nearest g) of muskellunge populations from the Ohio River drainage and North Spring Lake, IL introduced in Lake Mingo during fall 2002. The Ohio River drainage stock is represented by the Kentucky Cave Run Lake population and the Illinois muskellunge are North Spring Lake, IL progeny. Vertical lines represent 95% confidence limits.

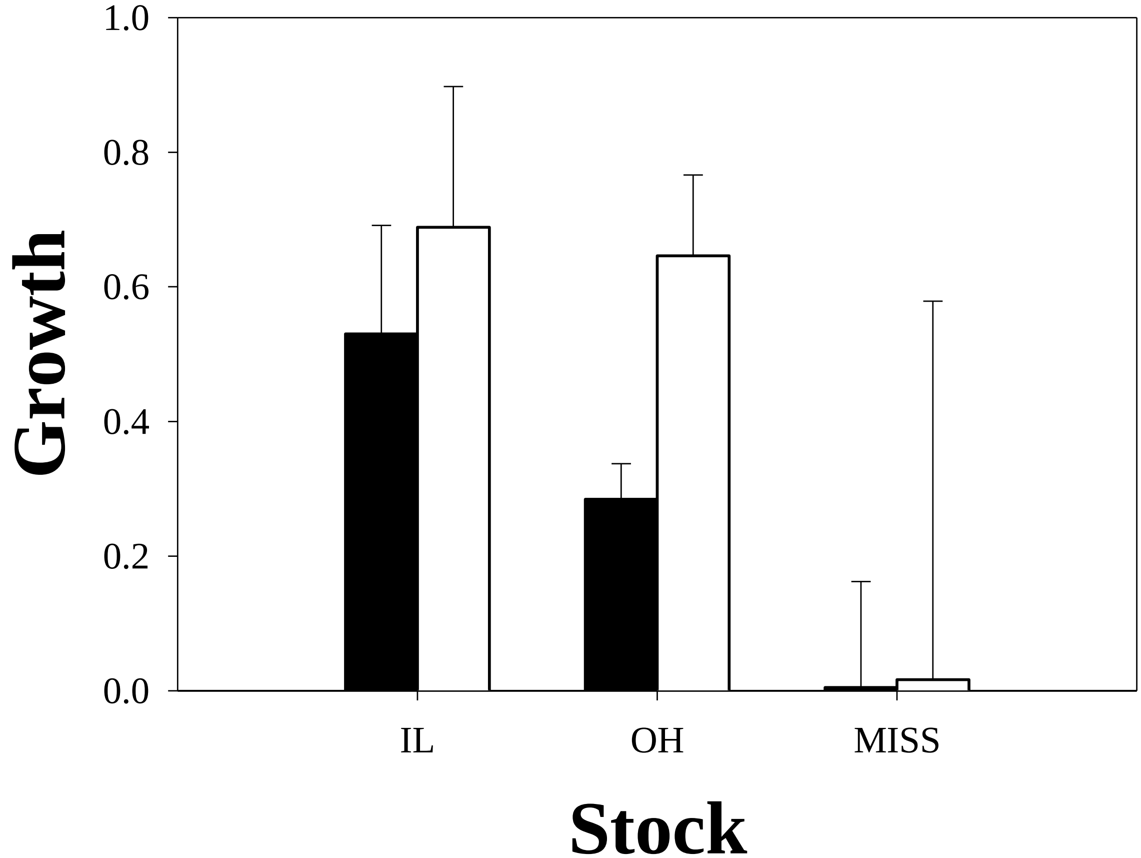


Figure 4. Mean daily growth rates (g/d, solid bars) and mean relative growth rates (g/g/d X 100, open bars) of three stocks of muskellunge introduced in Pierce Lake during fall 2003. Growth is presented from the time of stocking through spring (March through May 2004). Vertical lines represent 95% confidence limits.

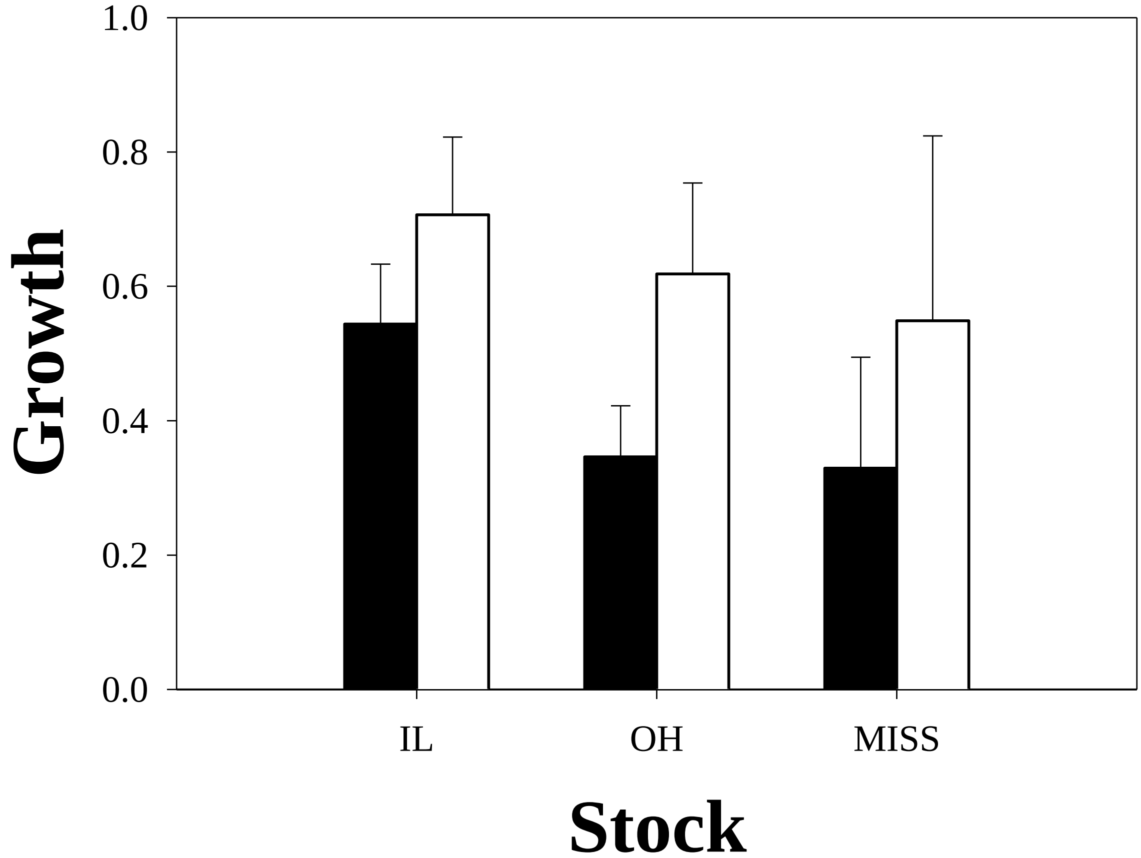


Figure 5. Mean daily growth rates (g/d, solid bars) and mean relative growth rates (g/g/d X 100, open bars) of three stocks of muskellunge introduced in Lake Mingo during fall 2003. Growth is presented from the time of stocking through spring (March through May 2004). Vertical lines represent 95% confidence limits.

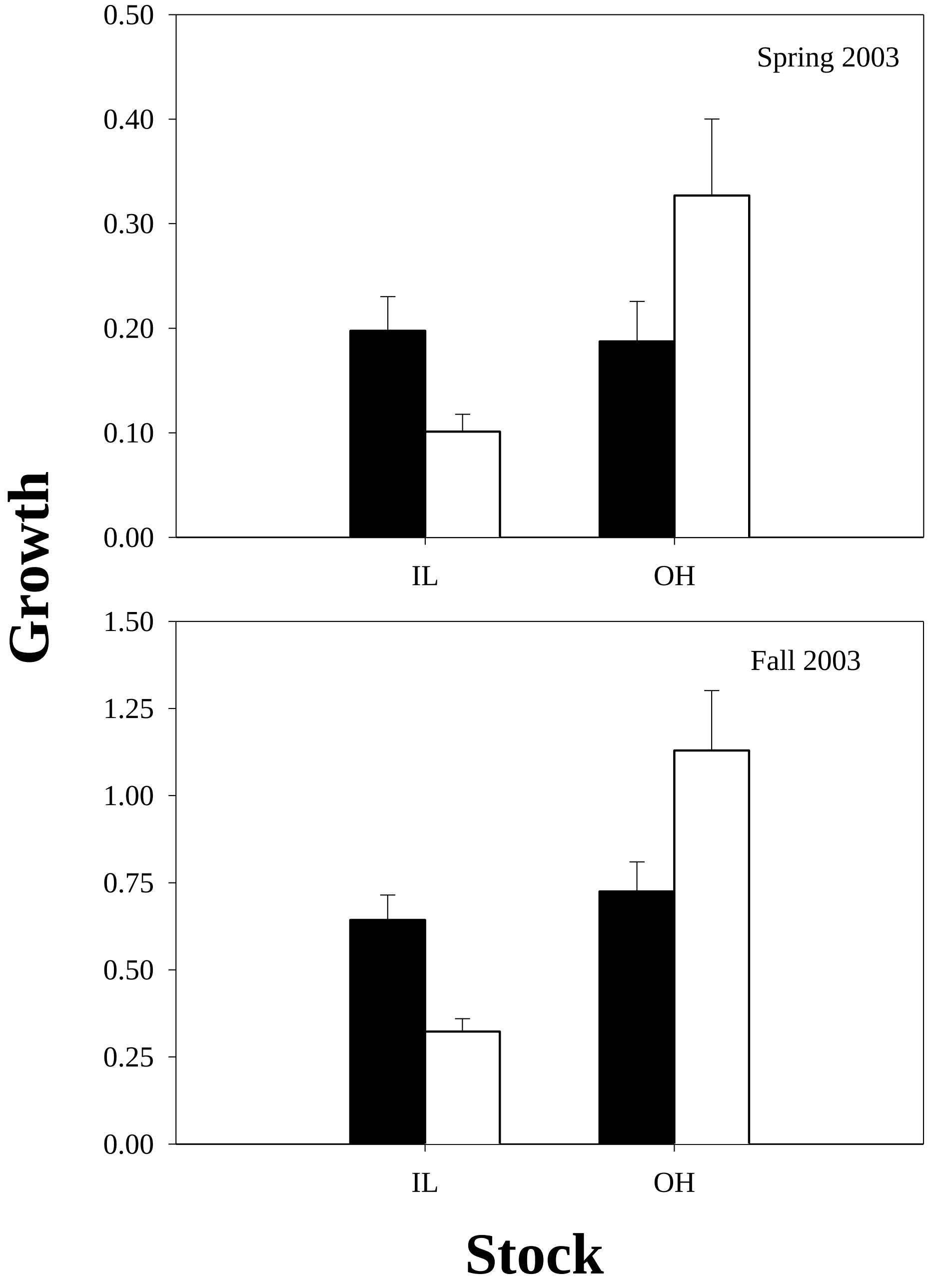


Figure 6. Mean daily growth rates (g/d, solid bars) and mean relative growth rates (g/g/d X 100, open bars) of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2002 and drained during April 2003 and again in October 2003. The top panel represents the 6-mo growth from stocking until April 2003 and the bottom panel represents the 1-yr growth from stocking until October 2003. No Mississippi River drainage stock muskellunge were recovered in any of the ponds and therefore no growth values are given. Vertical lines represent 95% confidence limits.

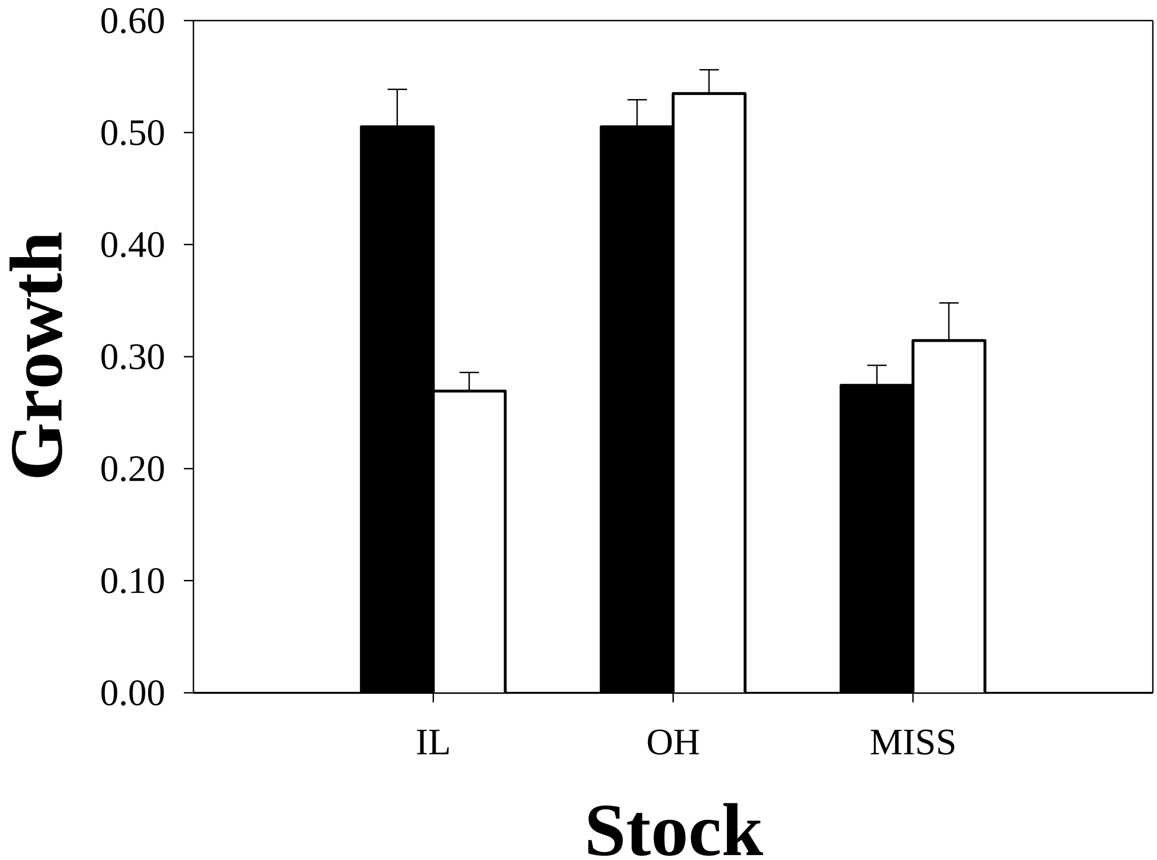


Figure 7. Mean daily growth rates (g/d, solid bars) and mean relative growth rates (g/g/d X 100, open bars) of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2003 and drained during April 2004. Vertical lines represent 95% confidence limits.

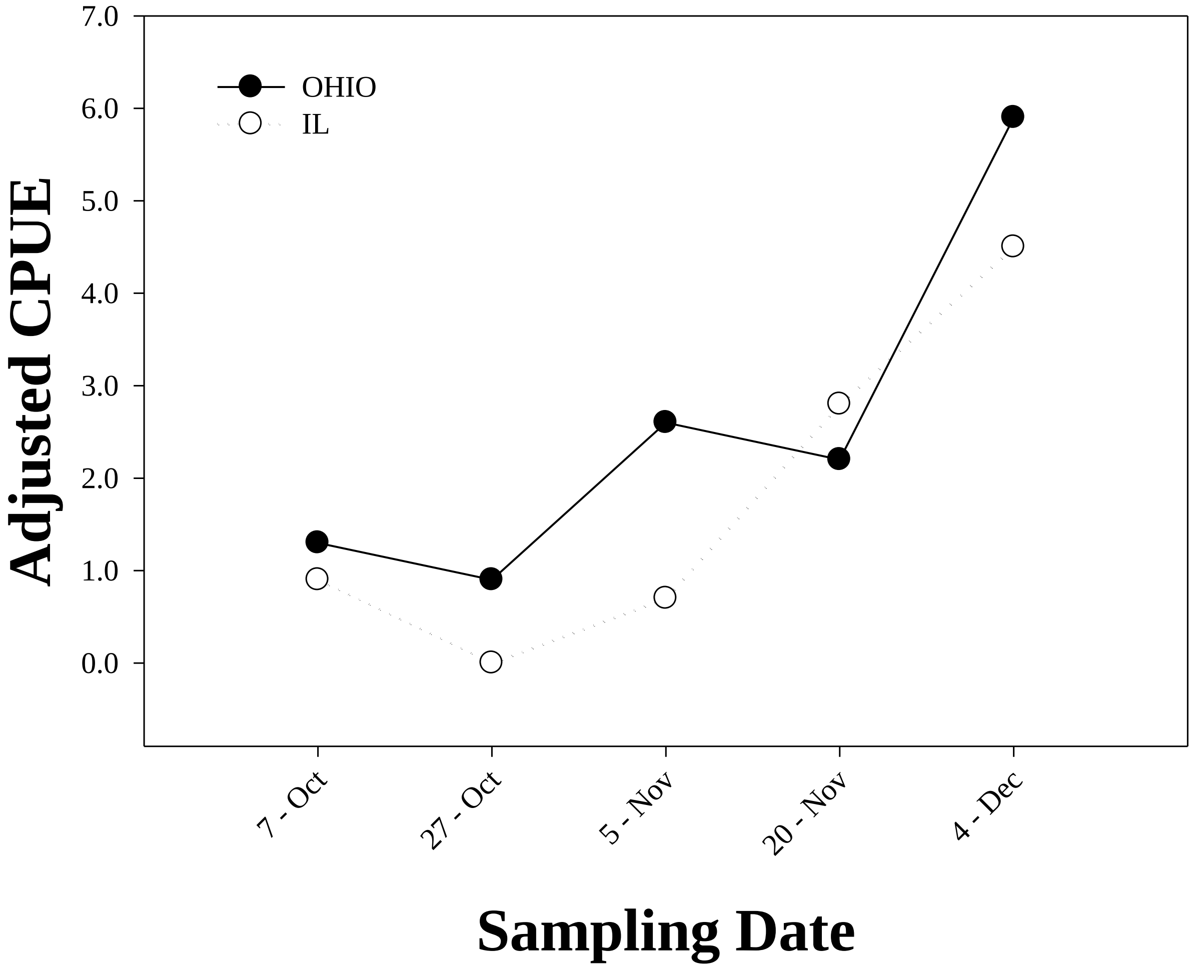


Figure 8. Adjusted catch-per-unit-effort (CPUE) through time for the Ohio River drainage stock (OH), and the North Spring Lake, IL progeny (IL) muskellunge introduced in Lake Mingo during fall 2002. Sampling was conducted from October through December 2003. The CPUE of the Ohio River drainage stock is adjusted to account for varying stocking numbers (Adjusted CPUE).

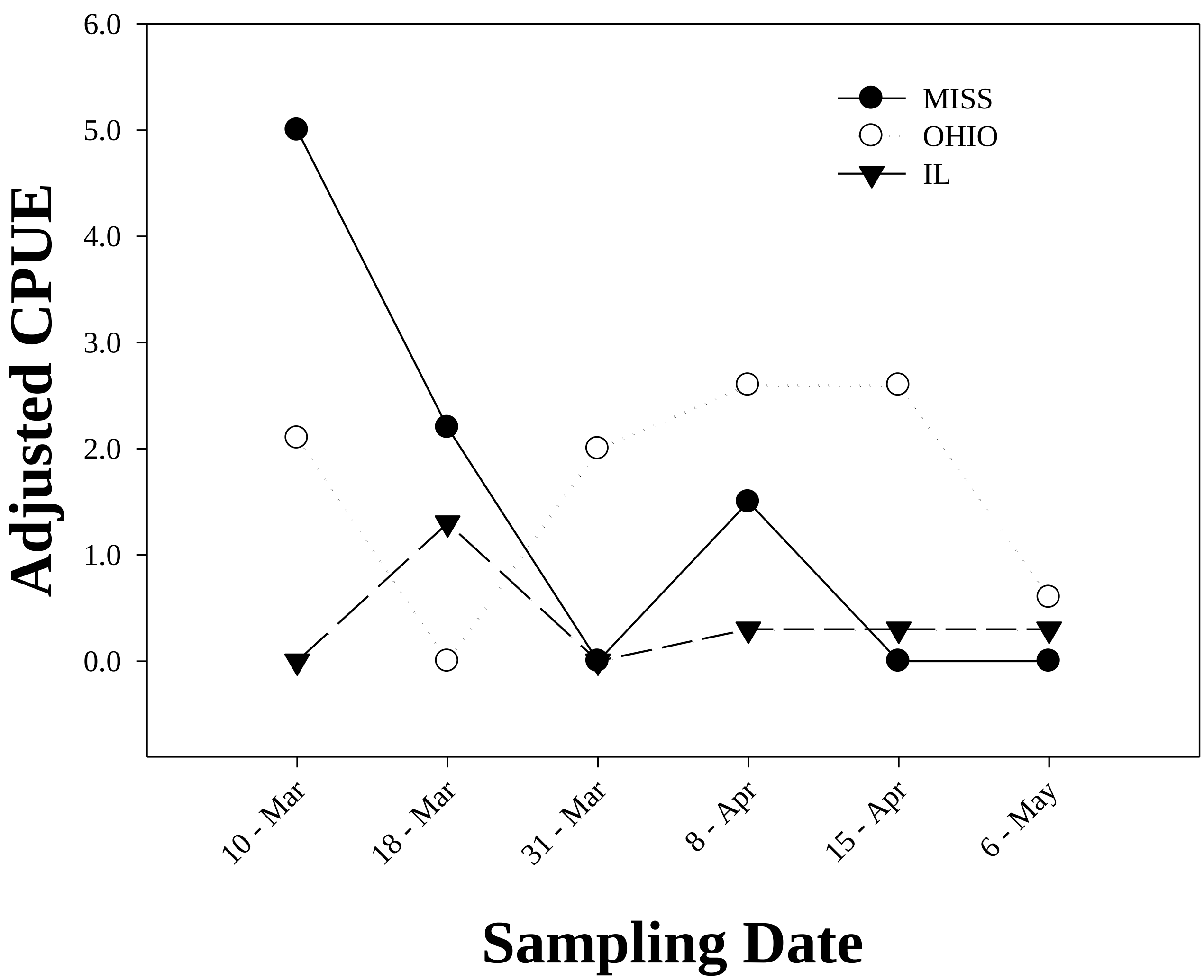


Figure 9. Adjusted catch-per-unit-effort (CPUE) through time for the Upper Mississippi River drainage stock (MISS), the Ohio River drainage stock (OH), and the North Spring Lake, IL progeny (IL) muskellunge introduced in Pierce Lake during fall 2003. Sampling was conducted from March through May 2004. The CPUE of the Upper Mississippi River drainage stock and the CPUE of the Ohio River drainage stock are adjusted to account for varying stocking numbers (Adjusted CPUE).

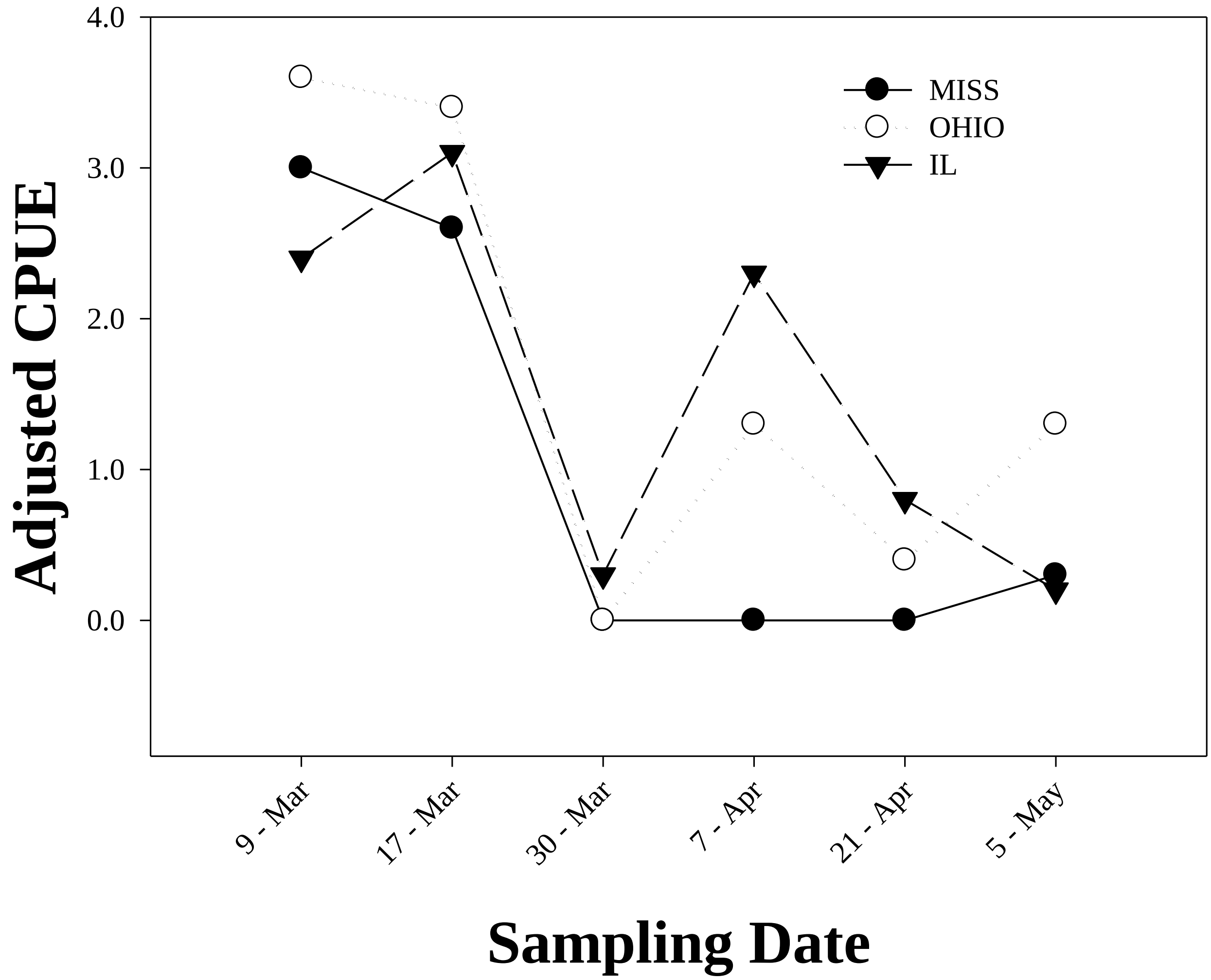


Figure 10. Adjusted catch-per-unit-effort (CPUE) through time for the Upper Mississippi River drainage stock (MISS), the Ohio River drainage stock (OH), and the North Spring Lake, IL progeny (IL) muskellunge introduced in Lake Mingo during fall 2003. Sampling was conducted from March through May 2004. The CPUE of the Upper Mississippi River drainage stock and the CPUE of the Ohio River drainage stock are adjusted to account for varying stocking numbers (Adjusted CPUE).

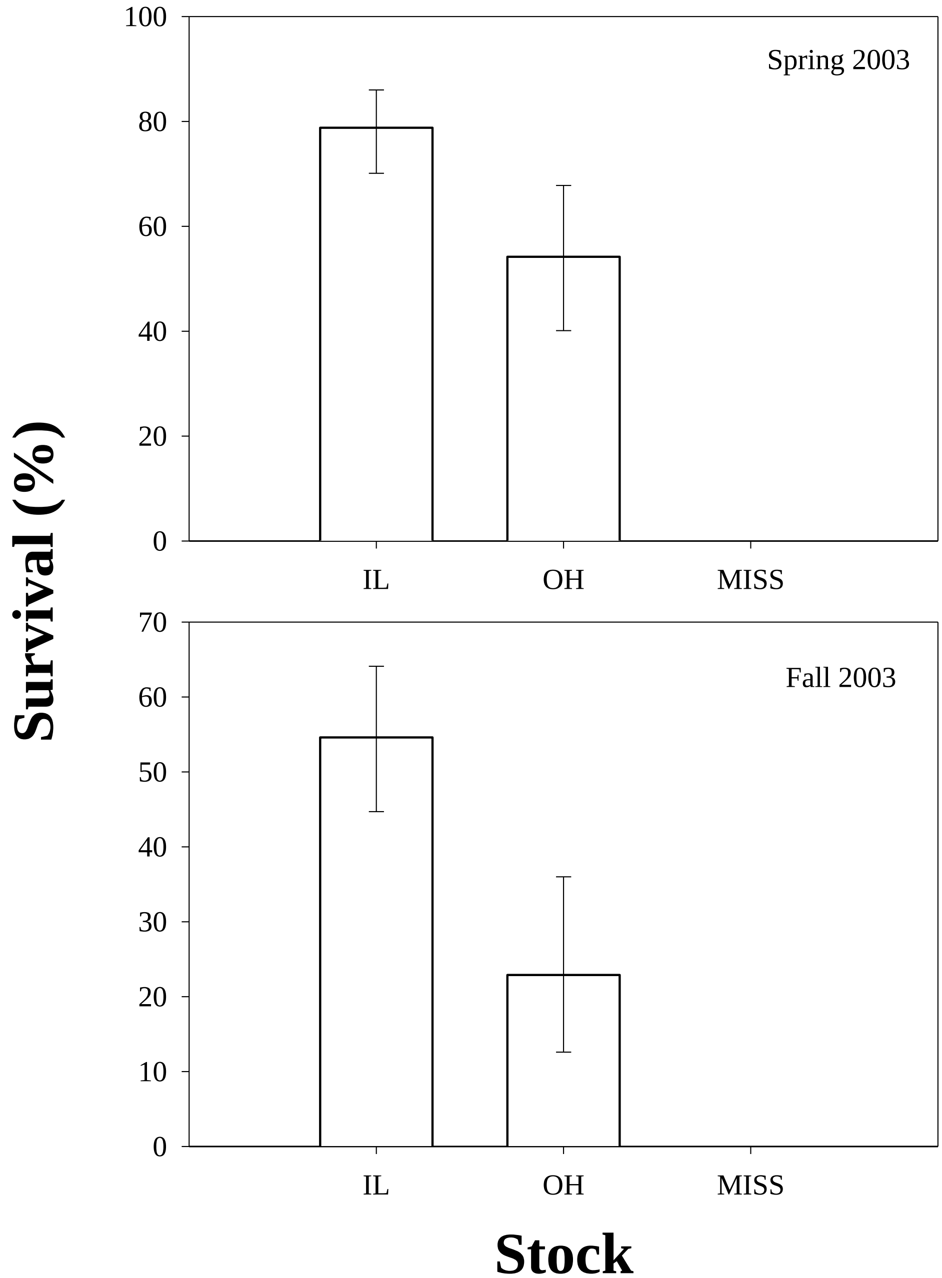


Figure 11. Survival of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2002 and drained during April 2003 and again in October 2003. The top panel represents the 6-mo survival from stocking until April 2003 and the bottom panel represents the 1-yr survival from stocking until October 2003. No Mississippi River drainage stock muskellunge were recovered in any of the ponds. Vertical lines represent 95% confidence limits.

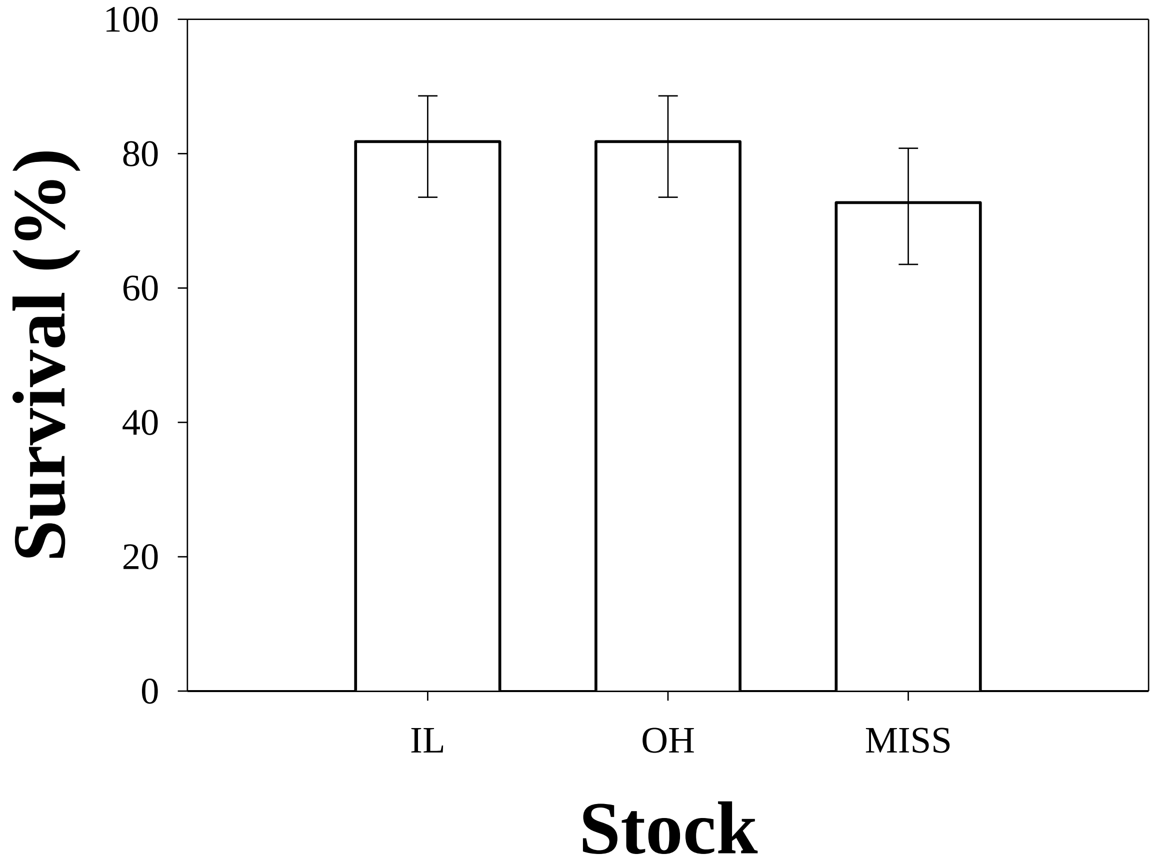


Figure 12. Survival of three stocks of muskellunge introduced into 3, 0.4-ha ponds in October 2003 and drained during April 2004. Vertical lines represent 95% confidence limits.